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Parametric design of an automated kinetic building façade using BIM: A case study perspective

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ABSTRACT

Pollination plays a critical role in maintaining human life and its importance has been widely recognized by researchers. However, as the world population grows, construction activities have increased, leading to an expanded carbon footprint that has adverse effects on the environment. This has resulted in the loss of natural habitats for pollinators. To address these issues, this research aimed to design an innovative mixed-use building to promote biodiversity conservation. The building was designed to have global visibility and to combine various elements in different locations to achieve maximum functionality. Automated features were incorporated into the building's structure to enhance its efficiency. Throughout the project, experts were consulted to ensure the building met sustainability standards and the best site was selected. BIM was used as part of the research methodology to design the building and calculate its sustainability and energy-efficient elements. As a result, the building achieved Gold certification status and has made a significant contribution to green building and sustainability in the built environment. The final product not only addressed the biodiversity issue, by designing a building where honeybees and humans coexisted but also provided a new solution for future developments in sustainable design. To ensure that these efforts are successful, it is important for different sectors, including Architectural, Engineering, Construction, and Operations (AECO), to work together to create a more sustainable future for the planet.

1. Introduction

Architecture has been shaped by contemporary culture and the needs of society throughout history. In modern times, given the negative implications of global warming, such as rising sea levels, storms, droughts, and excessive heat waves, eco-architecture or green architecture has become a prominent expression of our values and concerns. With increasing awareness of environmental sustainability, buildings have come under scrutiny as major polluters, impacting the environment and surrounding areas [1]. As a result, the approach to building design is changing all around the world, where principles of USGBC LEED-rating systems are becoming more predominant, providing efficient and sustainable solutions that have become a global trend [2]. The intent is to adapt and conform to sustainability fundamentals by offering efficient and viable solutions to this issue, making it a virtue of necessity to address the CO_2 emissions produced by buildings and to combat the effects of global warming. Subsequently, the green element has taken a leading role as a contouring agent; it has become one of the main elements of the entire architectural and construction process, with rising demand for sustainable design [3].

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Furthermore, with the rising population, there have been increases in building construction and carbon footprint. The world's population is expected to reach six billion by 2045, which will result in more construction activities [4]. According to Lazar and Chitra [5], infrastructures consume 50% of global energy and contribute to more than 30% of global CO_2 emissions, making green buildings one of the imperative factors worldwide. Therefore, this will have a negative impact on both human life and wildlife, endangering many species to the point of extinction, including bees and pollinators. Pollination is a critical aspect of urban structures that has gained the attention of urban planners, researchers, and different localities [6]. Pollination is extremely important for the ecosystem, which helps the food chain and is a major contributor to the existence of natural landscapes [7]. For example, Toronto has initiated a Pollinator Protection Strategy to protect different kinds of bees and other pollinators, to preserve pollination and biodiversity, contributing to resilient ecosystems [6]. The Toronto project aims to provide opportunities for the creation of green and co-living-friendly spaces for pollinators across the city.

Given the importance of sustainability and pollination, there is a need for innovative building structures that address these global issues in practical ways. Moreover, there is a lack of practical solutions to address this issue in terms of planning, design, and construction around the world. Most studies discuss lowering CO_2 emissions without considering how it would be applied to all stages of the construction process, including building operation and maintenance [4]. Additionally, while most designs and studies focus on constructing typical greenhouses, there have not been many innovative approaches that could address this topic for cities on a large scale. As Ksiazek et al. [8] indicate, most research in this area only discusses the environmental effects of green roofs, and little is discussed in terms of the ecological utility that they can offer.

To address the above knowledge gaps and to procure a creative solution for pollination, the energy efficiency of buildings, and the reduction of Greenhouse Gas Emissions, a conceptual framework for a design of a skyscraper in Brussels was developed through a case study approach. This approach involved analyzing existing structures and projects, identifying successful design strategies, and applying them to the design of the proposed skyscraper. The case study method allowed the design team to draw from a variety of real-world examples and best practices, and to tailor the design to the specific context and needs of the project. The result was a conceptually sound and informed design solution for a skyscraper in Brussels, based on a thorough understanding of the opportunities and challenges posed by the project's site and surrounding environment.

This study introduces a unique and significant contribution to the body of knowledge by proposing a new, innovative design concept for a skyscraper that operates as a beehive and commercial office space, prompting coexistence between bees and humans, with the primary objective of preserving the phenomenon of pollination and biodiversity. Furthermore, the incorporation of LEED principles, the application of different technologies such as sensors, wind turbines, and PV panels, and the unique design of the kinetic façade of the structure are unequivocally of great importance towards a more sustainable built environment. Therefore, this research offers a new perspective on the construction and design processes, reinvigorating the trend towards green buildings and pollinating buildings.

2. Research objective

This study aims to incorporate technological solutions through the application of BIM tools to define an innovative building design based on LEED principles, addressing the current pollination problem in the world. It intends to achieve this goal by developing a multi-functional building structure that serves as a commercial office space and a beehive through a case study, where breeding honeybees can coexist with humans, and further assist the farmers during the pollination season. To fulfill the design intent of the multi-functional capacity of the building structure, and to meet the sustainability goals in terms of energy efficiency and reduced CO_2 emissions, this research proposes an application of wind sensors, thus creating innovative design solutions that enhance sustainability. The usage of wind sensors will aid in the creation of an automated kinetic façade feature, allowing the building frames to open and close based on weather conditions, the number of honeybees, and the time of the day. The main feature of this project lies in its dualism, based on both architectural and functional building elements.

3. Literature review

The purpose of this literature review is to examine the current state of research on the integration of pollination, kinetic façades, energy efficiency, Building Information Modeling (BIM), construction technology, and Leadership in Energy and Environmental Design (LEED) in sustainable building design. The integration of these elements has the potential to contribute to the development of more sustainable and energy-efficient buildings, while also promoting biodiversity and environmental health. Therefore, the following four dimensions are reviewed: pollination, kinetic façade, energy, BIM and construction technology, and LEED in sustainable building design.

3.1. Pollination

Several studies have explored the potential of incorporating pollination into building design. For example, a study by Dyer investigated the use of green roofs for pollination, finding that they can support a diverse range of insect species and improve local biodiversity [9]. The integration of kinetic façade into building design has also been explored, with a focus on improving energy efficiency. A study by Lee analyzed the use of kinetic façades in tall buildings, finding that they can reduce energy consumption by up to 20% with shading and ventilation strategies [10]. Pollination is an example of a well-studied ecosystem service that has been repeatedly described as being threatened by changes in land usage [11–18]. Animal pollination is an important service for communities with wild plants [12,19] as well as agricultural ecosystems [20]. Many crops depend on or benefit from pollination, mostly done by domesticated honeybees, along with wild pollinators such as wild bees, bumblebees, butterflies, hoverflies, or in some cases, vertebrates such

as bats and birds [21], and according to Ridzuan et al. [22], flower-based plants increased the number of insects and pollinators in urban areas. Although the three crops with the highest production globally, i.e., rice, maize, and wheat, do not require animal pollination, over a third of the world's crop production still relies on pollinators, and approximately 75% of all crop species see some degree of benefit from animal pollination, including most vegetables, fruits, and spices [21]. These crops that depend on or benefit from pollination are crucial for providing essential nutrients in human diets [23]. There is clear evidence of a loss of wild and domestic pollinators [11–18], which has a range of negative ecological and economic impacts, including a decline in wild plant diversity, ecosystem stability, food production, and human well-being. The main drivers of pollinator's decline are the loss and fragmentation of semi-natural habitats and other anthropogenic disturbances such as the increase in usage of pesticides, pollution, the spread of pathogens, introduced species (alternative plant species, competitors, or enemies), and climate change [24]. As it has been stated based on the current research, pollination is on the decline, and preventive measures are needed to address this issue within the context of the built environment. Blaydes et al. [25] suggest that proper management of solar parks could assist with the improvement of pollinator biodiversity. Ahmad, Wang, & Hazell [26] recommend the usage of bio-friendly construction materials for a more sustainable environment. Other studies point out the creation of grass-based green roofs in urban settings to preserve pollinators [27,28].

3.2. Kinetic façade and energy

One of the most well-known smart façades is the kinetic façade. It is of utmost importance to design and develop façades that are interactive and responsive to the characteristics of the environment. These façades, which belong to the so-called intelligent façades, can adjust their shape, orientation, or openings to automatically respond to environmental parameters such as temperature, humidity, wind, etc. [29]. According to Wiggington and Harris [30], studies in building intelligence have shown that the façade performs various functions that influence the passage of energy from the external environment to the internal environment and vice versa. They identified the manipulating functions as follows: (1) enhancing daylight, e.g., light wells/reflectors; (2) maximizing daylight, e.g., full height glazing or atria; (3) protection, e.g., blinds or shutters; (4) insulation, e.g., night shutters; (5) ventilation, e.g., automatic dampers; (6) collection of heat, e.g., solar panels; (7) dissipation of heat, e.g., overhangs or brise-soleil; (8) attenuation of sound, e.g., acoustic dampers; (9) generation of electricity, e.g., photovoltaics; (10) the use of pressure differences, e.g., ventilation chimneys. Furthermore, experimentation with kinetic and buildings' architectural skins is increasingly implemented as a solution for environmental design issues, as façades and elements are transformed into kinetic living beings that change in harmony according to their surroundings [31]. For instance, buildings with kinetic and architectural coverings are becoming increasingly popular as a solution to environmental design challenges. With an increasing concern for sustainability and energy efficiency, architects and engineers are looking for new solutions to lessen the buildings' environmental effects. The usage of kinetic skins has been found to be a viable answer, which may adapt to external environmental stimuli such as wind, sunshine, and temperature. Kinetic skins may manage internal climatic conditions, minimize energy consumption, and improve the building's visual appeal by dynamically altering the building's façade [32]. Additionally, in recent decades, technologies have evolved considerably by integrating specific elements to adapt outdoor conditions to the needs of the occupants [33]. In general, façades are designed to respond to many scenarios and perform functions that may contradict each other: daylighting versus energy efficiency, ventilation versus views, and energy generation [34]. Because of these sustainable stimulants, small-scale renewable energy technologies have become increasingly important in the construction industry, and many governments have set targets for electricity generation from these renewable resources [35,36]. Despite low wind speeds and high turbulence that are usually encountered in urban areas, there is an increasing trend in research and development for the application of adaptive wind energy systems in the built environment. Many studies have been conducted to evaluate the wind resources in the urban environment and to overcome the challenges associated with the application of wind energy harvesting systems, including the low speed and high turbulence of urban wind, the difficulties of building installation, and the vibration and noise challenges [37–41]. It is commonly believed that buildings also provide flow acceleration and higher turbine placement, which increases power generation [42,43].

3.3. BIM and construction technology

Architectural, Engineering, Construction, and Operations (AECO) techniques are evolving rapidly; however, this evolution is always outpaced by new demands that seem to grow even faster. Large infrastructure projects are becoming more common, which requires firms to develop new tools for creating and maintaining plans and documents and to manage changes and information exchange during the design process. Existing drafting software such as AutoCAD is being used to manage and modify plans as needed. However, this technology is being gradually replaced by Building Information Modeling (BIM), which offers a great advantage in terms of data integration and information-sharing [44].

Nederveen et al. [45] described BIM as “a model of information about a building that comprises complete and sufficient information to support all lifecycle processes, which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components and comprises information about properties such as function, shape, material, and processes for the building life cycle” [46]. Building Information Modeling (BIM) has been implemented in the construction industry for the past 25 years for the many benefits it offers [45,47]. “BIM as a digital information management system is one of the most significant and promising changes in the AEC industry”, which is considered a ‘paradigm shift’ that is utilized for information management during design and the entire project life cycle [48]. The term BIM was coined by Professor Charles M. Eastman in the 1970s and it translates into ‘computer-based modeling of a generic building design.’ It is based on a process that organizes all the performance information [49]. Further, BIM is a modern way of designing construction projects using data, diagrams, and technical documents in an organized and efficient manner compared to traditional methods [50]. It is not only a three-dimensional representation but also a common model that represents the first step in the development of the Architecture, Engineering, Construction, and Owner Operators (AE-

COO) industry in the world. To this end, the concept of BIM is being extended to disciplines for which it was not originally intended [51,52]. Its success is mainly due to a new planning approach that allows for the design and management of the whole life cycle of a project, including other dimensions and useful information such as project schedule, project cost, clash detection, and other simulations [53]. In UNI 11337-4 (2017) [54], each element of the project is associated with a specific LOD. This acronym corresponds to two concepts: "Levels of Development" and "Levels of Detail". The first one is a representation of the geometric elements along with the information associated with them, while the second refers to the level of detail of the BIM model itself. The process is based on three levels of classification: the first consists of 2D models in form the of CAD, the second is in 3D format, and the third is related to the concept of BIM [55]. Another useful feature when working on a project is Autodesk Revit software archives, which can be used to create system families. The family editor allows the users to edit them graphically and create parametric relationships between their geometries. It also allows the user to create 'loadable' or 'local' families. It is not possible to create a 'system' family instead, because those are not useful in a sense of being more rigid and have predefined parameters that work only through special dialogs [56]. Additionally, Autodesk products are extremely useful for the design and energy analysis of buildings that enable designers to conduct different evaluations throughout the building lifecycle, including Autodesk Insight, Revit, and Green Building Studio [45]. One of the advantages of BIM is the ability to share a platform, API, that allows external applications to be integrated. BIM-based software such as Revit, Rhino, and Grasshopper allow external factors to be assigned to a BIM model [57]. By using the applications of BIM, designers get a more integrated and visualized view of building performance in the early stages of the design phase. As for the energy performance of buildings, BIM can calculate and analyze the whole energy consumption using parameters stored in a database, in contrast to traditional assessment methods that are very time-consuming and labor-intensive [58]. Given the invaluable benefits of BIM tools and its prominent usage by the industry, as stated above, the authors found BIM to be the best analysis option for this research.

3.4. LEED in sustainable building design

Buildings consume a significant amount of energy, which affects the built environment during the construction phase [59]. Therefore, sustainable buildings with environmentally friendly and energy-efficient structures have been proposed to reduce the environmental impact of buildings, save energy, and water, and contribute to the health and comfort of occupants through practices such as temperature and humidity control, indoor air quality, natural lighting, and waste handling [60]. Due to the growing demand for sustainable development and green buildings in recent years, green building rating systems have been introduced to assess the life cycle performance of buildings. These certification programs are revolutionizing the way cities and communities are planned, developed, and operated to improve the quality of life for people around the world. These programs provide a framework for planning, designing, measuring, and managing the performance of social, economic, and environmental conditions at city or community levels. Leadership in Energy and Environmental Design (LEED), one of the most well-known and widely used green building rating systems, was developed by the U.S. Green Building Council (USGBC) [61]. Therefore, its application in design, credit analysis, and documentation that are submitted to achieve the required type of certification [62] is significant within the research community [63].

LEED® uses an online rating system that awards points for site selection, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, sites and connections, innovation in design, and regional priority. When the scores are combined, successful projects are categorized as 'Certified' in different categories such as Silver, Gold, or Platinum [64]. Assessment of energy efficiency of buildings with regards to LEED principles is becoming more common and being incorporated into the design of today's infrastructure around the world. BIM has played a great role in the design and calculations of energy towards sustainable LEED principles. Many studies have used BIM for LEED assessments. Jalaei et al. [65] proposed a BIM-integrated solution for the calculation of LEED credits. Rehman et al. [66] designed a parametric model in Revit to design a building based on LEED principles. Atabay et al. [67] used BIM tools for the design and construction phases of a university project, while [68] economic benefits of BIM in green building projects. The incorporation of BIM and LEED can make a significant contribution to sustainability efforts using accurate measurement for design and its cost-saving potential.

4. Research methodology

The research methodology comprises the utilization of Building Information Modeling (BIM) tools for the conceptual design of an automated kinetic building façade of a multi-purpose skyscraper building which functionally provides space for commercial office space and serves as a beehive for pollination purposes. The building design included the usage of wind turbines, and ultrasonic and piezoelectric sensors to make it function as an automated kinetic façade. In addition, it employs different aspects of innovative technologies for sustainable design based on LEED principles, including the usage of energy efficiency criteria, which were incorporated during the design phase to have the building achieve LEED Gold certification. The proposed conceptual framework and design were implemented based on a case study approach on a site in Brussels. The case study offers a new direction for future research to tackle the pollination problem by utilizing innovative design solutions. Based on the design intent, the following steps were conducted as part of the methodology and then applied to the case study: (1) Agronomy and beekeeping experts were consulted to provide technical support for the selection of green ad hoc for the project, (2) Site selection was implemented based on cultural, environmental, and social attributes deemed suitable for the project, and (3) BIM tools were utilized for the design of the project. The research framework of the study is shown in Fig. 1, and the profile of the experts is shown in Fig. 2 below.

4.1. Site selection

The location for the project development was primarily influenced by social, cultural, and environmental factors. Although there were a different range of available options, the choice fell almost spontaneously on Brussels. The first motivation was to consider the

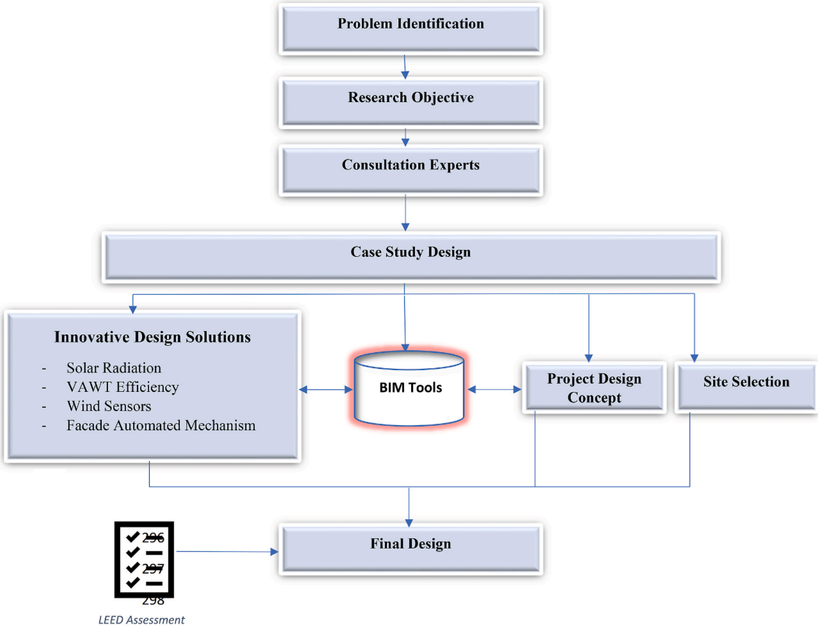

Fig. 1. Research framework.

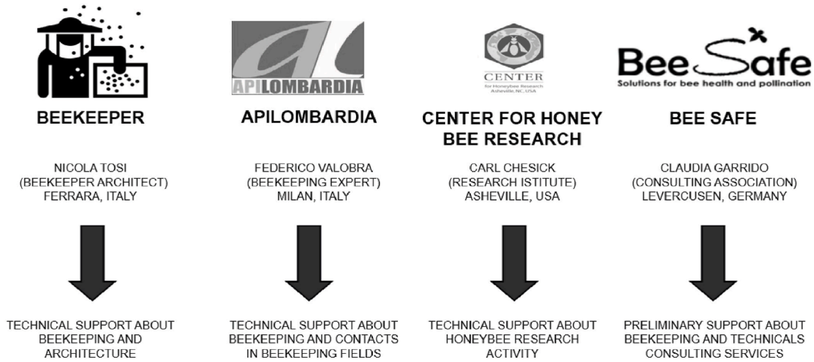

Fig. 2. Profile of experts.

most influential and active body regarding this issue, i.e., the European Union. This choice provides a solid basis for future developments, having more visibility, authority, and economic means necessary to give the project international recognition. The main decision-making goal was to design not only an architectural organism but also a manifesto of change, of course, on a global scale. Therefore, the decision was not to conduct the research in a rural setting, but where it could have the greatest impact on the daily lives of most citizens, i.e., on the outskirts of the historic center of the European capital and the seat of the main EU institutions. This not only allows for the highest possible visibility from the media and political standpoint, but also outlines the possibility of creating a new organization for the conservation and development of biodiversity and pollinators that can work in symbiosis with the institutions of the European Commission, some of whom are already actively working in this field. The first phase of analysis was based on an experimental research project called 'OKMO', initiated, in the past, by new media artist, Annemarie Maes [69]. She is the founding director of the Urban Bee Lab in the territory of Brussels, whose aim was to study the behavior, deficiency, and possibilities of beekeeping and apiculture in urban, metropolitan areas. Moreover, given that the city of Brussels is characterized by a low skyline, vertical development has allowed it to leave a recognizable trace in the urban fabric. Considerations were made to establish a relationship with the nearby historic center to preserve the historic and cultural integrity of the city. From an aesthetic point of view, the envelope of the tower is designed as a replica of a beehive to characterize the intention and purpose of the new building; to communicate the evolvement from an architectural element to a manifesto directly to the users on a large scale.

The selection of the area that suited the needs and purpose of the project was based on various parameters and expertise. The starting point was to limit the selection to urban areas capable of providing the basic conditions for the presence and health of bees, i.e., green areas along with an unlimited source of water, such as the canal. This allowed us to limit the choices for site selection to the areas crossing the Charleroi-Brussels canal. This was based on the result of an analysis, known as the Canal Plan, described in detail in the government program of the Brussels-Capital Region, which aims to implement and promote development and regeneration mea-

sures along the axis of the canal. Additionally, a second analysis was conducted, reviewing possible urban development programs in the region such as PRDD (Plan Regional De Dèveloppement Drable), PAD (Plan d'Amènegement Directeur), ZEMU (Zone d'Entrepises en Milieu Urbain), ZRU (Zone de Revitalisation Urbaine) and ZEUS (Zone d'Économie Urbaine Stimulée). By overlapping these urban development plans and considering areas of the OKMO project in Brussels, as well as the foraging range of honeybees within a 3-km radius [70], the Porte de Ninove area was chosen as the final site for the project. The project area in Brussels and the project sites are shown in Figs. 3 and 4, respectively.

The next step of the process started with a census of the native flora of Brussels, using the bibliography and sitography sources provided by the city and the European Union, and further selections were made based on the most favorable plants that were attractive to the bees. This process helped with the creation of a more realistic landscape, and justified the presence of bees, hives, and beekeepers within the building to maximize the health and reproduction of greenery and bees within the building, as well as the entire urban fabric of Brussels.

4.2. Design process using software

The initial design process of the project involved two stages: (1) the Grasshopper plugin was used in Rhino 3D and (2) the design was transferred into Revit. The design team attempted to import the Rhino file into Revit, decompose it, and then categorize the planes and façades using Revit families. However, this approach proved to be unsuccessful. As a result, the project was designed using Revit from the outset as shown in Fig. 5. Additionally, some issues arose while designing the façade in Revit since the façade had a hexagonal pattern. Three different options were undertaken, out of which two did not provide accurate results, not having the same sizes and coordinates comparable to that of Grasshopper. Therefore, the Grasshopper plugin was linked with Revit to transfer the same coordinates using an Excel file and then the hexagonal family was designed and imported into the project, as shown in Fig. 6. The project was also geolocated in the Revit software with the ability to perform different types of analyses, using different applications and plug-ins, including Dynamo, Grasshopper, and Autodesk Insight, that considered the parameters of the project site, as shown in Fig. 7. As a result, this allowed for climatic and environmental analyses to be conducted to optimize and implement the technical and architectural decisions as objectively as possible.

5. Case study results

The project design and development process are presented in detail in this section, showing the final product and how the methodology was applied to the case study project. This section includes the design, application of innovative technologies, and analysis of LEED status.

5.1. Project design concept

The decision to use the architectural typology of the skyscraper was not accidental. Nowadays, the concept of a skyscraper is no longer tied only to the parameter of height, but also to the concept of an iconic landmark. The spatial and material dimensions of space often merge with their intangible value. Indeed, the volumetric yield acquires a communicative and expressive value, allowing glass, steel, and concrete to represent a brand, a company, or an owner along with the values and missions that underlie a theme. From an urban planning perspective, a skyscraper also has its dignity, creating a dialog and relationship with the landmarks of the urban fabric. In this case, the need to create a manifesto for a global European trend and a movement was inevitable; to have a concrete

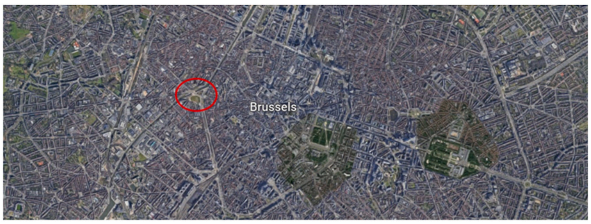

Fig. 3. Project area in Brussels. Source: https://goo.gl/maps/JeoUwvQuEytnUESg9.

Fig. 4. Aerial view of the project site.

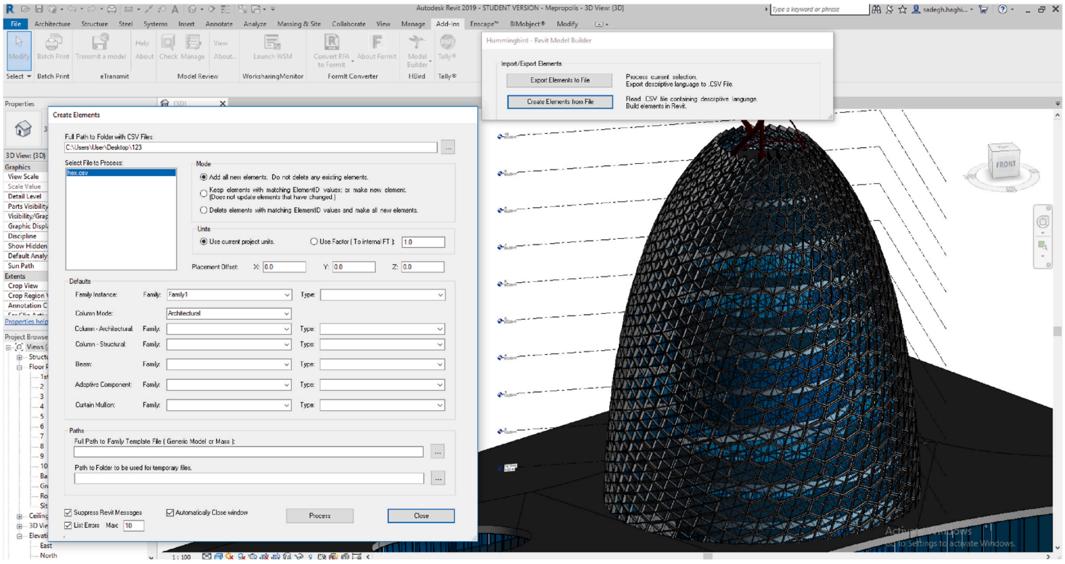

Fig. 5. Project design in Autodesk Revit.

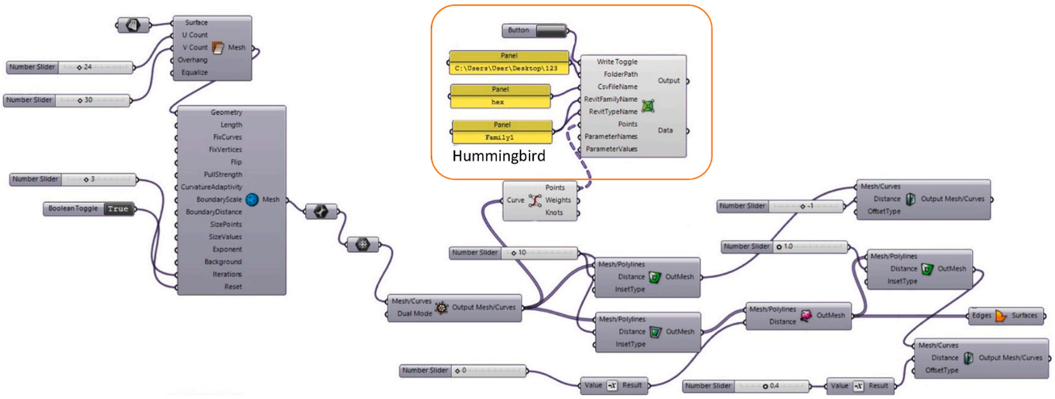

Fig. 6. Grasshopper linked to Autodesk Revit.

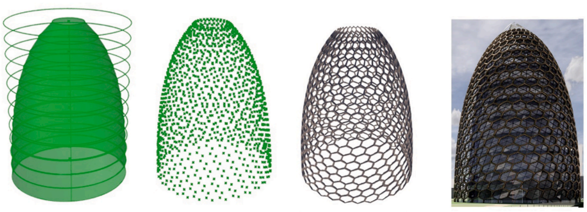

Fig. 7. Design analysis of the structure in Revit.

structure, functioning as a protecting agent for pollination and the planet, combined with the social, urban, political, and communicative value of this type of architecture. The vertical section of the building, as shown in Fig. 8, was divided into two macro-areas: (1) the internal section which consisted of labs and office spaces that were closed off, and (2) the external section which housed the bees hives with automated capabilities for opening and closing to the outside, allowing the bees to enter and leave the building. These two areas are separated by a glass façade to preserve the view from the inside of the building and to direct the light from the south to office spaces. The façade of the building is a self-supporting structure and is technically separated from the interior structure. The material used for the façade is steel. The hives were placed on the terraces of the building, accessible from different floors to the beekeepers, who are responsible for the research and care of the bees, representing the contact element between these two worlds. In addition, the location of the terraces was linked to the complementary internal functions that are most closely associated with them, such as the laboratories, the beekeeping school, and the monitoring offices. These secondary relationships aimed to establish a direct relationship between the different users, therefore, reducing the distances between different actors collaborating on this process. Lastly, the resi-

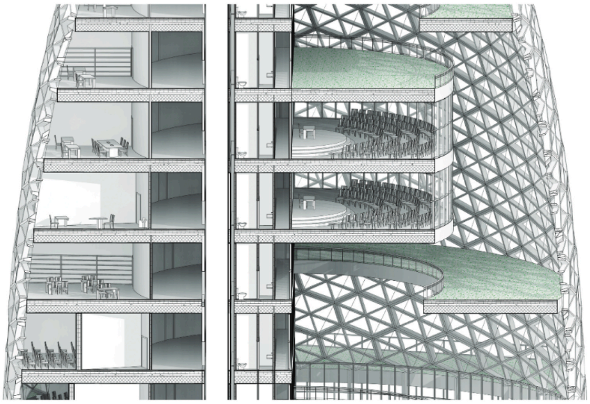

Fig. 8. Vertical view of office space and beehive.

dents can also enjoy observing this spectacle and interaction between bees and beekeepers, which is rarely seen in a metropolitan context, with large windows, in a controlled environment. Fig. 9 shows the positions and the relationships of all stakeholders in the building.

5.2. Technology, wind sensors, kinetic façade, structure

The materials and technologies utilized in the building played an important role in the project. An attempt was made to employ an innovative approach by giving value to technological aspects with special emphasis on protecting pollinators. Although the main materials used in the layers of the building are widely used in construction, including cement, wood, and steel, the façade was designed with special automation systems and manufacturing processes. The outer shell was designed based on a preliminary study of the volume and organization of the hives, opting for a system of cells with a hexagonal shape. In addition to being directly inspired by the structure of beehives, this compositional system has numerous other features. From a structural point of view, the hexagonal pattern allows for optimizing and relieving stresses along the individual elements that are composed, offering the possibility of creating a self-supporting structure. In addition, the grid system consisted of uniform elements that allow great freedom in the development of the individual, automated and mobile elements, with the advantage of adapting the building for different types of usages should the need arise during the life cycle of the project.

Based on different analyses such as speed of the wind, position, and height of the building, sunlight exposure, along with other conditions related to the bees' survival, given their sensitivity to the wind and foraging factors for pollination, the design of a kinetic façade was deemed to be appropriate. The solar radiation and wind pressure analysis were conducted using Grasshopper and Autodesk Flow Design, as shown in Figs. 10 and 11 respectively. The kinetic façade functions according to the time of the day and weather conditions, making it a multifunctional, automated feature, which controls the airflow inside the building and the traffic of honeybees in the south elevation accordingly. The kinetic façade automated mechanism is shown in Fig. 12. To control the kinetic façade according to the wind flow, two different types of sensors are used in the façade of the building, namely, piezoelectric sensors and ultrasonic sensors. When the wind blows, the ultrasonic sensors send a pulse or a command to the central control unit (MC-AVR) to close the frames. However, to ensure that all the bees can return to the nest before the frames are completely closed, the piezoelectric sensors estimate the number of bees, based on their buzzing sound while inside the building, considering honeybees fly at an average speed of 15 miles per hour [71]. Depending on how many bees return to the building, the kinetic façade begins to close proportionately according to the number of bees, which is not based on a linear relationship, but rather in the form of a parabolic graph. Once all the bees have returned to the nest, the façade will close completely. Moreover, the energy for the kinetic façade is generated by the Vertical-Axis Wind Turbine (VAWT) system, which optimizes energy efficiency by saving electric energy for future usage. Depending on the size of the turbine and the speed of the wind in Brussels, it generates between 15 KWH to 20 KWH, as shown in Fig. 13.

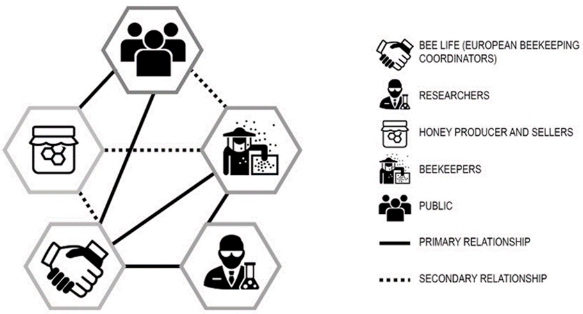

Fig. 9. Relationships between stakeholders.

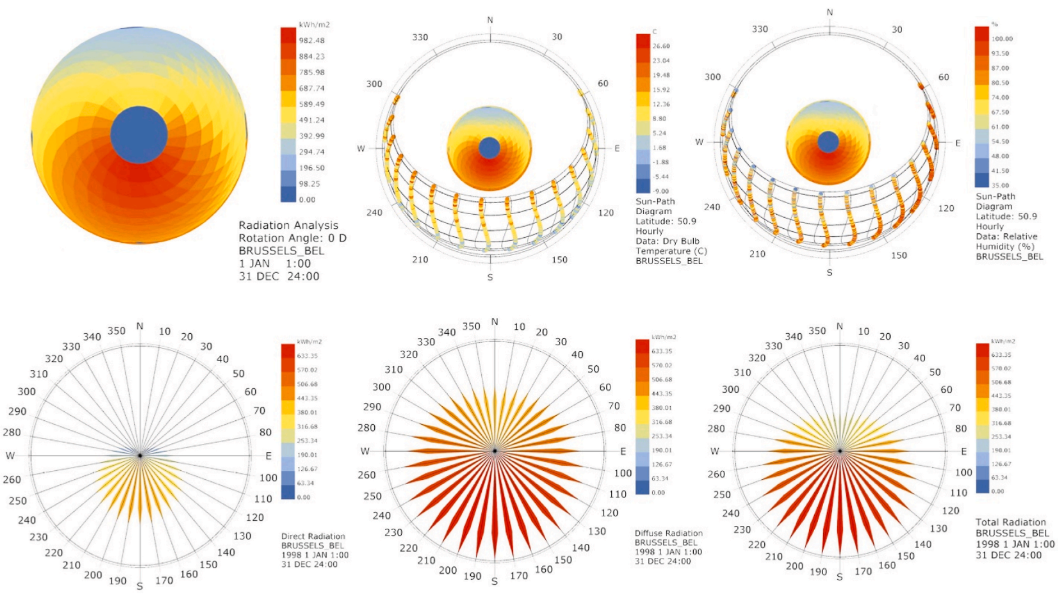

Fig. 10. Analysis of solar radiation in Grasshopper.

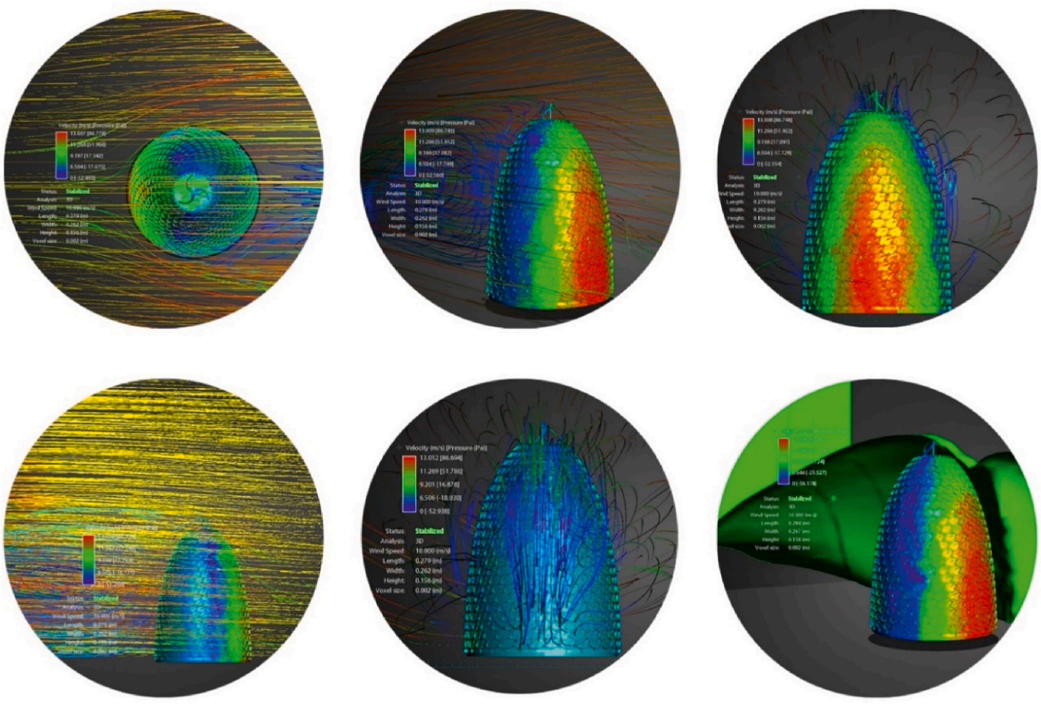

Fig. 11. Wind pressure analysis in Autodesk Flow Design.

There is a second option for energy production and usage in the building, and that is via a PV panel system, which is installed on the roof, and placed within the last two frames of the façade. The calculation of the amount of generated electricity is dependent on the size, location, slope, and azimuth of the panels. The energy yield of PV panels was calculated on the European Commission's website [54] as shown in Fig. 14.

Furthermore, all the different technologies that were implemented in the building structure are shown in Fig. 15 and defined below.

Kinetic Façade is an automated feature that functions based on weather conditions and air flow, controlling the traffic of honeybees in and out of the building.

Central Unit controls the kinetic façade based on the signals it receives from the sensors.

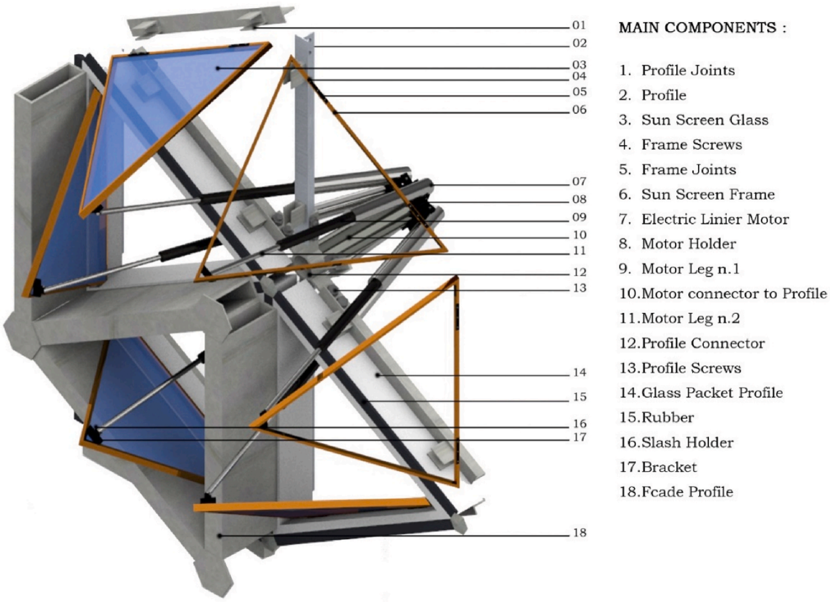

Fig. 12. Kinetic façade automated mechanism.

Piezoelectric Sensors are used in the building project described in the passage to estimate the number of bees inside the building. they generate an electrical charge when subjected to mechanical stress, such as pressure or vibration, detecting the buzzing sound generated by the honeybees.

Ultrasonic Sensors control the opening and closing of the frames based on the speed of wind by sending a signal to central control.

Vertical-Axis Wind Turbine (VAWT) generates energy for the kinetic façade by saving electric energy for future usage.

PV Panels produce additional electricity for the building.

5.3. LEED certification

Following the preliminary design phase, it was possible to carry out a series of certified assessments to understand the strengths and weaknesses of the building. The first analysis that was performed was related to the Active House assessment, which gives an overall picture of the building from an energy and environmental perspective. The result showed better performance in the respective categories where BIM was utilized. This shows the usefulness of these applications to optimize the performance of the building. However, this type of evaluation was mainly used in the initial phase of the process. After the final design, an assessment was carried out using LEED certification to provide a general overview of the validity of the design decisions made. This assessment was made based on the various systems and technologies that were incorporated in the building such as energy-efficient lighting, HVAC systems, and water management systems, and how they contributed to the overall performance of the building. As for the heating and cooling system, an air-water system was used to optimize the peculiar resources present in the site such as the wind, the river, and the sun. The wind was used as a main resource since it is the most present element in the territory of Brussels. At the top of the tower, a small wind turbine system was placed as stated earlier to utilize the southeast wind within the project area. The elevation of this system, although limited, has allowed the exploitation of the low skyline of the city, not having significant volume encumbrances in the direction of the wind in front of the building. Additionally, the river, in addition to being a vital resource for bees, was utilized as a sustainable and readily available source of water for the air-water system. Moreover, a system of photovoltaic panels, as described earlier, was placed on top of the façade along the entire perimeter, to take advantage of direct and indirect radiation throughout the day. This choice allows us to compensate for most of the electricity needed for the heating and cooling system and for the motorized opening system of the individual cells that make up the façade. The end elements of the system were then delegated to fan coil units. They were only installed in the parts of the building intended for human occupation since bees, having evolved according to climate change, can survive the local climatic conditions.

The results obtained based on the systems explained above led to a gold rating. Nevertheless, the certification also highlighted some aspects that could be improved in the final phase of the building. Fig. 16 shows the evaluation of the building performance by USGBC to achieve a Gold-certified status.

6. Discussion & limitations

The researchers acknowledged that the magnitude of the problem prevented a simple hypothesis. Initially, the problem seemed limited to a specific field of expertise; however, after implementation, it was clear that a system of chain reactions and scholarly interactions, involving many disciplines, was required to address the issue. Previous studies have mainly focused on the decline of pollina-

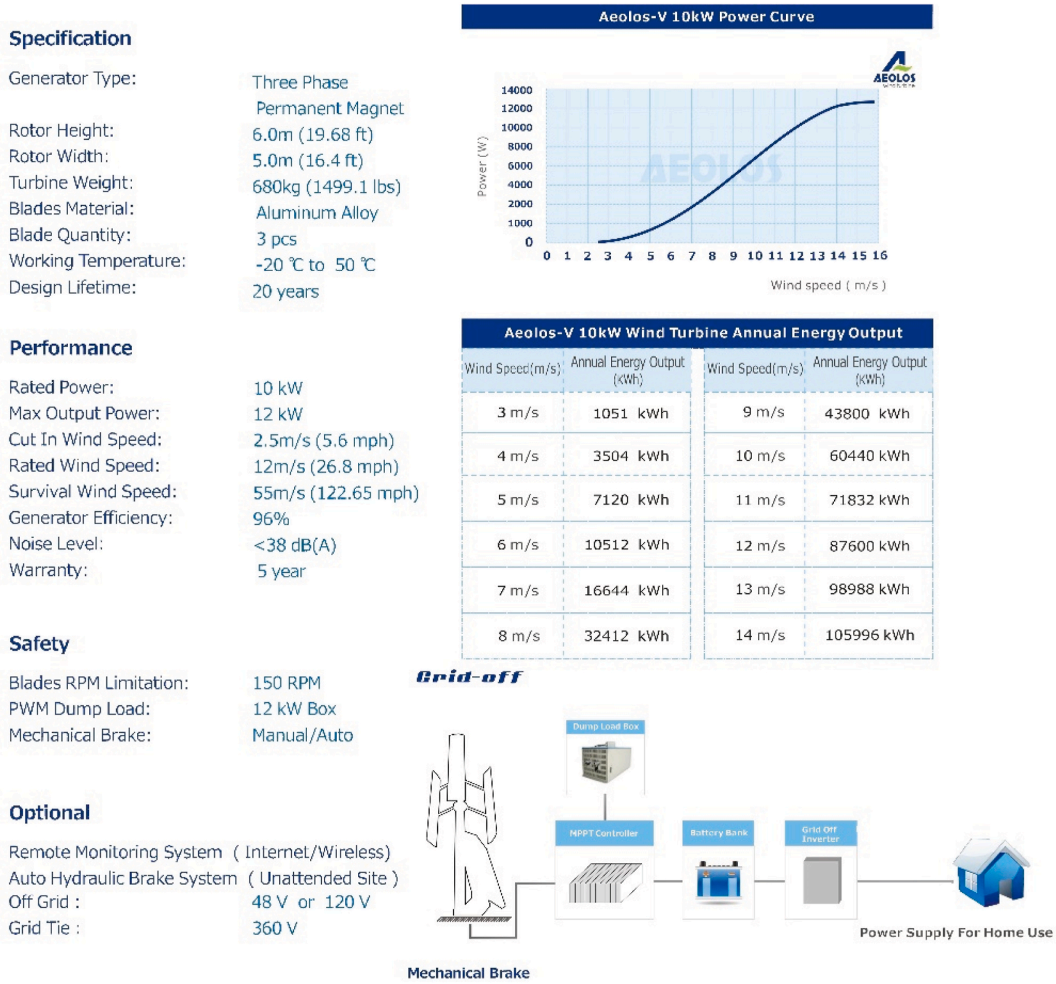

Fig. 13. VAWT Efficiency Calculation based on Location and Annual Wind Flow. Source: https://www.windturbinestar.com/10kwv-v-aeolos-wind-turbine.html

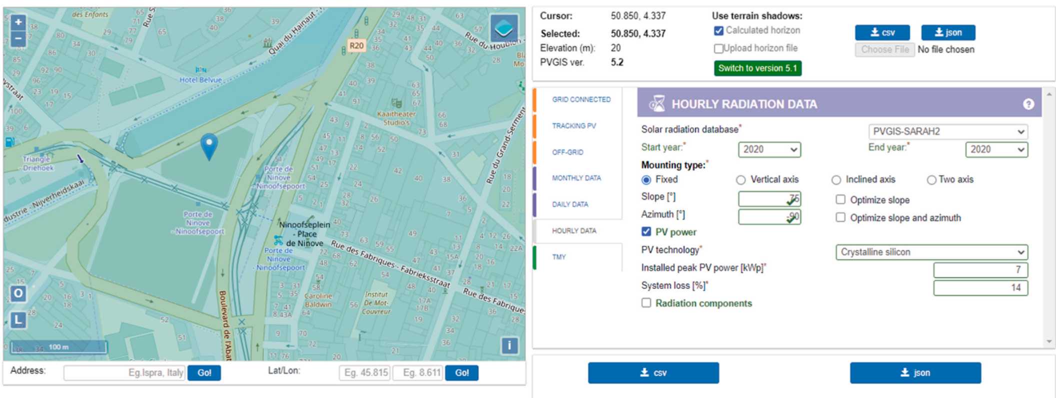

Fig. 14. PV efficiency calculation for Brussels. Source: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html [72].

tion because of man-made structures. Others have recommended the usage of sustainable materials to preserve the environmental effects of pollination, while some have suggested how green roofs and flower plants in or near buildings could assist with the enhancement of pollinators. However, this study proposed a new solution where pollinators could coexist with humans in an urban setting, thus directly impacting the preservation of pollinators. This study is a starting point for future developments and interdisciplinary projects in the field of architectural design and its role in addressing environmental challenges. The findings and proposed solutions of this study highlight the importance of changes in construction policies, practices, and further support the theory to fully utilize the

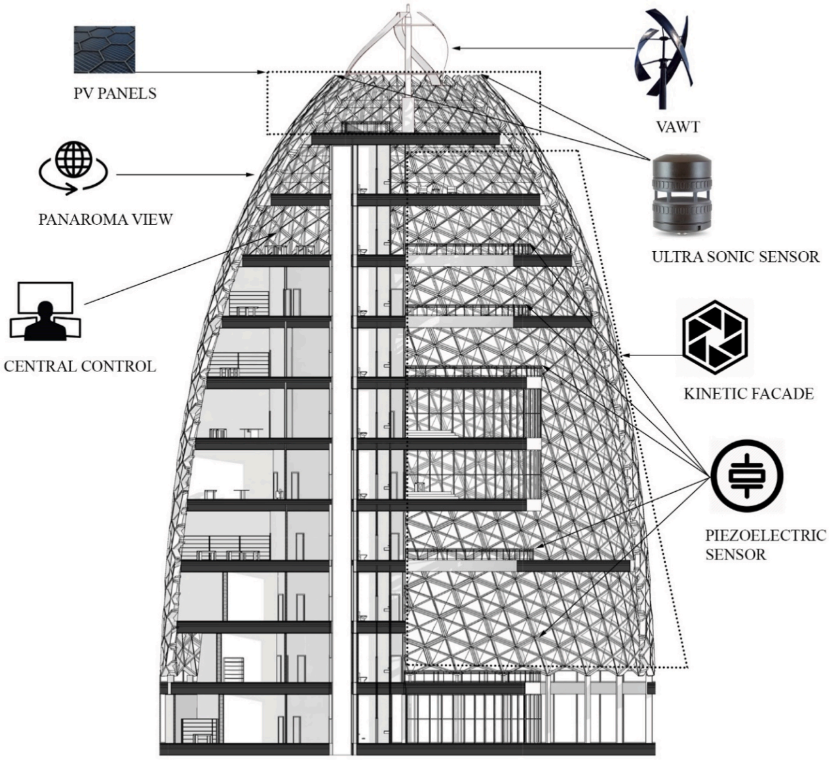

Fig. 15. Application of technologies incorporated in the building.

LEED v4 for BD+C: New Construction and Major Renovation
Project Checklist

Project Name: MEPROPOLIS
Date: 11/19/2021
Members: Sadegh Haghighat, Hooman Sadeh

Y	?	N				BIM App Y	BIM App ?	BIM App N
			Credit	1	1			
14	0	1	**Location and Transportation**		16	3	2	1
1			Credit	LEED for Neighborhood Development Location	16			1
1			Credit	Sensitive Land Protection	1		1	
2			Credit	High Priority Site	2		1	
4		1	Credit	Surrounding Density and Diverse Uses	5	1		
3			Credit	Access to Quality Transit	5			
1			Credit	Bicycle Facilities	1	1		
1			Credit	Reduced Parking Footprint	1	1		
1			Credit	Green Vehicles	1			
4	0	2	**Sustainable Sites**		10	6	0	0
Y			Prereq	Construction Activity Pollution Prevention	Required	Y		
1			Credit	Site Assessment	1	1		
		1	Credit	Site Development - Protect or Restore Habitat	2	1		
1			Credit	Open Space	1	1		
		1	Credit	Rainwater Management	3	1		
1			Credit	Heat Island Reduction	2	1		
1			Credit	Light Pollution Reduction	1	1		
7	1	1	**Water Efficiency**		11	0	0	0
Y			Prereq	Outdoor Water Use Reduction	Required	Y		
Y			Prereq	Indoor Water Use Reduction	Required	Y		
Y			Prereq	Building-Level Water Metering	Required	Y		
1			Credit	Outdoor Water Use Reduction	2			
5		1	Credit	Indoor Water Use Reduction	6			
	1		Credit	Cooling Tower Water Use	2			
1			Credit	Water Metering	1			
23	6	2	**Energy and Atmosphere**		33	0	0	0
Y			Prereq	Fundamental Commissioning and Verification	Required	Y		
Y			Prereq	Minimum Energy Performance	Required	Y		
Y			Prereq	Building-Level Energy Metering	Required	Y		
Y			Prereq	Fundamental Refrigerant Management	Required	Y		
5			Credit	Enhanced Commissioning	6			
12	6		Credit	Optimize Energy Performance	18			
1			Credit	Advanced Energy Metering	1			
1			Credit	Demand Response	2			
1		2	Credit	Renewable Energy Production	3			
1			Credit	Enhanced Refrigerant Management	1			
2			Credit	Green Power and Carbon Offsets	2			
11	0	1	**Materials and Resources**		13	5	0	0
Y			Prereq	Storage and Collection of Recyclables	Required	Y		
Y			Prereq	Construction and Demolition Waste Management Planning	Required	Y		
5			Credit	Building Life-Cycle Impact Reduction	5	1		
2			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2	1		
2			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2	1		
2			Credit	Building Product Disclosure and Optimization - Material Ingredients	2	1		
		1	Credit	Construction and Demolition Waste Management	2	1		
12	0	1	**Indoor Environmental Quality**		16	6	3	0
Y			Prereq	Minimum Indoor Air Quality Performance	Required	Y		
Y			Prereq	Environmental Tobacco Smoke Control	Required	Y		
1			Credit	Enhanced Indoor Air Quality Strategies	2		1	
1			Credit	Low-Emitting Materials	3		1	
1			Credit	Construction Indoor Air Quality Management Plan	1		1	
2			Credit	Indoor Air Quality Assessment	2	1		
1			Credit	Thermal Comfort	1	1		
2			Credit	Interior Lighting	2	1		
3			Credit	Daylight	3	1		
1			Credit	Quality Views	1	1		
		1	Credit	Acoustic Performance	1	1		
2	0	0	**Innovation**		6	0	0	0
1			Credit	Innovation	5			
1			Credit	LEED Accredited Professional	1			
0	4	0	**Regional Priority**		4	0	0	0
	1		Credit	Regional Priority: Specific Credit	1			
	1		Credit	Regional Priority: Specific Credit	1			
	1		Credit	Regional Priority: Specific Credit	1			
	1		Credit	Regional Priority: Specific Credit	1			
73	11	8	**TOTALS**	Possible Points:	110			

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

Fig. 16. LEED evaluation. Source: https://www.usgbc.org/leed [73].

potential of BIM in sustainable building design. To fully realize the potential of this study, and succeed in achieving the expected outcome, cooperation between different sectors, including Architectural, Engineering, Construction, and Operations (AECO), along with other relevant industries is necessary.

However, the study has some limitations and areas for future improvement. One limitation of this study was the lack of existing literature on this topic. While there have been many studies conducted on BIM, pollination, green roofs, and LEED, there is no similar research like what has been proposed by this study. The authors suggest that future studies should focus more on the relationship between beekeeping and urbanism and be implemented on smaller projects for more accurate measurements. This can be done by investigating the benefits of urban beekeeping on the urban environment and how beekeeping can be integrated into the urban fabric. Additionally, the study was limited to a specific site in Brussels, and its application may have limitations in other geographical areas. Therefore, future studies can implement smaller projects in different locations to gather more accurate measurements and assess the effectiveness of the proposed solutions in different contexts. In addition, while the study proposed an innovative design for a multi-purpose building for pollinators, it is important to explore the economic feasibility of such solutions. Future studies can investigate the costs and benefits of integrating beekeeping into building design and assess the potential economic impacts of these solutions. It is further recommended that the impact of these solutions be investigated on biodiversity. Future studies can assess how the proposed solutions affect the local ecosystem and whether they contribute to the conservation of biodiversity.

7. Conclusion

The study aimed to provide a new perspective and introduce a groundbreaking approach to the problem of pollination and biodiversity loss by conducting a critical analysis of the current challenges, proposing new solutions based on consultation with experts and a thorough analysis of existing knowledge. Further, the study introduced an innovative design for a multi-purpose building structure that served both as a beehive and office space for the first time, which is considered a key contribution of this research. Moreover, the structural and plant systems acted as filters and regulators among the different functions and spaces within and outside the building. In addition, the structure had an innovative design, which incorporated both automated and non-automated technologies to assist with pollination and was based on a set of parameters considering the specific needs and characteristics of urban users. The technological study of the materials and devices used in the project allowed for a unique and innovative solution, which can contribute to the development of similar projects in other locations. The use of BIM tools in the design and analysis process was another key contribution of the study, which played an essential role as the initial generator. The application of BIM demonstrated the usefulness of these tools in optimizing building performance, which was evident in achieving the LEED certification. BIM was further fundamental in producing a material object based on a set of parameters that considered the different needs and specificities of the users within the urban structure. Likewise, collaboration between professionals from various sectors, through numerous contributions, can have a great impact on the future of the built environment, solving environmental challenges by applying sustainability principles for the planet.

Author statement

We certify that all persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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